

**PROCESS FOR POLYMER HYDROGENATION USING LITHIUM HYDRIDE
PREPARED FROM REACTOR EQUIPPED WITH HIGH-SPEED INJECTION NOZZLE**

5 **CROSS REFERENCE TO RELATED APPLICATIONS**

 This application claims priority to Korean Patent Application No. 10-2003-0000403 under 35 U.S.C. §119.

BACKGROUND OF THE INVENTION

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 1. The Field of the Invention

 This invention relates to a process for polymer hydrogenation using, as a cocatalyst, a highly active lithium hydride prepared from a reactor equipped with a high-speed injection nozzle in a method for selectively hydrogenating the unsaturated double
15 bond in the conjugated diene unit of a conjugated diene polymer or a copolymer containing a conjugated diene by using an organotitanium hydrogenation catalyst.

 2. Related Prior Art

 There have been reported several methods for hydrogenating or selectively
20 hydrogenating the unsaturated double bond in conjugated diene polymer. For example, U.S. Patent Nos. 3,494,942; 3,634,594; 3,670,054; and 3,700,633 disclose methods of using an appropriate catalyst known in the prior art, particularly a catalyst or a catalyst precursor containing a group VIII metal for the sake of hydrogenating or selectively hydrogenating a polymer containing an ethylenic unsaturated double bond, or a polymer
25 containing aromatic and ethylenic unsaturated double bonds.

 The catalyst used in these methods is prepared by mixing a Group VIII metal (e.g., Ni or Co) compound with an appropriate reducing agent (e.g., aluminum alkyl). Here, the Group VIII metal compound is combined with Group I-A, II-A or III-B metal alkyl or hydride at a concentration sufficient to provide Group I-A, II-A and/or III-B metal to
30 Group VIII metal ratios within the range from about 0.1:1 to about 20:1, preferably from about 1:1 to about 10:1.

As suggested in the prior art, the hydrogenation catalyst is typically prepared by mixing a Group VIII metal compound with a reducing agent in an appropriate solvent or a diluent in the temperature range of 20 to 60 °C before it is added to the hydrogenation reactor.

5 U.S. Patent No. 4,501,857 reveals that the double bonds in a conjugated diene polymer can be selectively hydrogenated in the presence of at least one bis(cyclopentadienyl)titanium compound and at least one alkyl lithium compound.

U.S. Patent No. 4,980,421 also discloses that the similar activity of hydrogenation can be provided by adding a bis(cyclopentadienyl)titanium compound with an alkoxy
10 lithium compound at an appropriate mixing ratio, or mixing an alkoxy lithium compound, which can be used in combination with an alcohol or phenol compound, and a bis(cyclopentadienyl)titanium compound. According to this related document, the catalyst has such a high activity that it can be used in a small amount without adversely affecting the stability of the hydrogenated polymer, and the deashing step is not required in this
15 method.

U.S. Patent No. 4,673,714 discloses that a bis(cyclopentadienyl)titanium compound preferably hydrogenates the double bond of a conjugated diene without a need of using alkyl lithium. The specific examples of the titanium compound include a bis(cyclopentadienyl)titanium diaryl compound. As mentioned in the document, the
20 advantage of this catalyst system is that there is no need of using an alkyl lithium compound.

U.S. Patent No. 5,583,185 describes a method for hydrogenating the double bond of a conjugated diene in a living polymer using a homogeneous catalyst represented by the formula $\text{Cp}_2\text{Ti}(\text{PhOR})_2$ (where Cp is cyclopentadienyl; and OR is an alkoxy compound
25 having 1 to 4 carbon atoms) or Cp_2TiR_2 (where R is CH_2PPh_2), and an organic alkali metal compound as a polymerization initiator.

U.S. Patent No. 5,039,755 suggests a method for conjugated diene polymer hydrogenation that involves polymerizing or copolymerizing a conjugated diene monomer in the presence of an organic alkali metal compound as a polymerization initiator in an
30 appropriate solvent to produce a living polymer. The polymerization is terminated by the addition of hydrogen to the produced living polymer. The selective hydrogenation of the

double bond in the conjugated diene unit of the terminated polymer is performed in the presence of a catalyst represented by $(C_5H_5)_2TiR_1R_2$ (where R_1 and R_2 are the same or different and selected from the group consisting of C_1 to C_8 alkyl or alkoxy, or C_6 to C_8 aryloxy, arylalkyl, cycloalkyl, silyl or carbonyl). The hydrogenation step is performed
5 without an alkyl lithium or alkoxy lithium compound. From this patent, U.S. Patent Nos. 5,132,372 and 5,206,307 disclose the use of alkylbenzoate as an accelerator for enhancing the hydrogenation reaction.

In addition, U.S. patent application No. 09/555,161 suggests a method for selectively hydrogenating a conjugated diene that includes polymerizing or
10 copolymerizing at least one conjugated diene using an organic alkali metal as an initiator to prepare a living polymer, adding a terminating agent to deactivate the living terminal of the living polymer, and adding a lithium hydride and a monocyclopentadienyl titanium compound with hydrogen to the terminal-deactivated polymer to selectively hydrogenate the conjugated diene.

15 In the above-stated methods, particularly disclosed in U.S. Patent Nos. 5,039,755; 5,132,372; and 5,206,307, and U.S. patent application No. 09/555,161, the addition of lithium hydride as a reducing agent in a general batch reactor involves adding a hydrogen gas to the mixing container of alkyl lithium through a sparger, requiring a vigorous stirring at more than 1000 rpm so as to reduce the reaction time, and the end point of the
20 reaction is delayed with an increase in the scale of the reaction, increasing the particle diameter to rapidly deteriorate the activity of lithium hydride as a reducing agent. Accordingly, the use of the conventional batch reactor is disadvantageous in that the preparation of highly active lithium hydride having a precisely controlled particle diameter is impossible to realize on a commercial scale.

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SUMMARY OF THE INVENTION

In an attempt to improve the problems with the hydrogenation methods as disclosed in U.S. Patent Nos. 5,039,755; 5,132,372; and 5,206,307, and U.S. patent application No. 09/555,161 in aspect to production on a large scale, the inventors of the
30 present invention have figured out that, in the preparation of lithium hydride used as a reducing agent of the cocatalyst in the process of polymer hydrogenation, the use of a

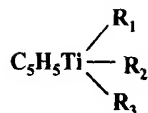
highly active lithium hydride having a precisely controlled particle diameter as prepared by adding hydrogen through a high-speed injection nozzle in a reactor and reacting the injected hydrogen with alkyl lithium can acquire stable hydrogenation reaction rate and hydrogenation reproducibility, improve the inefficiency such as long reaction time and
5 uneconomic aspect of requiring high pressure and high-speed stirring in the conventional method of reacting the active terminal of the living polymer or the alkyl lithium with hydrogen gas, and especially allow the quantitative control of the lithium hydride/titanium mole ratio in the hydrogenation of the conjugated diene polymer having different molecular weights, thereby maintaining a high hydrogenation activity.

10 It is therefore an object of the present invention to provide a method for polymer hydrogenation that uses a highly active lithium hydride having a precisely controlled particle diameter as prepared from a reactor equipped with a high-speed injection nozzle to acquire stable hydrogenation reaction rate and hydrogenation reproducibility, improve the inefficiency such as long reaction time and uneconomic aspect of requiring high
15 pressure and high-speed stirring in the conventional method of reacting the active terminal of the living polymer or the alkyl lithium with hydrogen gas, and allow the quantitative control of the lithium hydride/titanium mole ratio in the hydrogenation of the conjugated diene polymer having different molecular weights, thereby maintaining a high hydrogenation activity.

20 To achieve the above object of the present invention, there is provided a method for conjugated diene polymer hydrogenation that includes: polymerizing or copolymerizing at least one conjugated diene in a hydrocarbon solvent using an organic alkali metal polymerization initiator to generate a living polymer; adding a terminating agent selected from amines, esters, ketones or halogen compounds to deactivate the active
25 terminal of the living polymer; and selectively hydrogenating the conjugated diene polymer using at least one organotitanium compound represented by the following formula 1 and a highly active lithium hydride, which is prepared from a reactor equipped with a high-speed injection nozzle and thereby precisely controlled in regard to particle diameter:

30

Formula 1



where R₁ is selected from the group consisting of cyclopentadienyl, C₁ to C₈ alkoxy, C₆ to C₂₀ aryloxy, or halogen; and R₂ and R₃ are the same or different, and selected from the
5 group consisting of halogen, C₁ to C₈ alkyl or alkoxy, C₆ to C₂₀ arylalkyl or aryloxy, or C₇ to C₂₀ alkoxyaryl or carbonyl.

Now, the present invention will be described in further detail as follows.

The hydrogenation process of the present invention follows the known method of selectively hydrogenating a conjugated diene polymer using an organotitanium compound
10 represented by the formula 1 as a main catalyst, and lithium hydride as a cocatalyst. The lithium hydride used as a cocatalyst is a highly active lithium hydride having a precisely controlled particle diameter.

More specifically, the hydrogenation process includes a first step of polymerizing at least one polyolefin, particularly diolefin, or copolymerizing at least one polyolefin with
15 at least one alkenyl aromatic hydrocarbon monomer to prepare a copolymer containing both an ethylenic unsaturated double bond and an aromatic unsaturated double bond.

The copolymer can be of a structure random, tapered, block or a combination of these as well as linear, star-like, or radial.

The copolymer containing both an ethylenic unsaturated double bond and an
20 aromatic unsaturated double bond can be prepared by using an anionic initiator or a polymerization catalyst, such as an organolithium compound. The preparation method of the polymer can be a known method, e.g., bulk, solution, or emulsion polymerization.

The specific examples of the conjugated diene anionically polymerizable may include conjugated diene compounds containing 4 to 12 carbon atoms (e.g., 1,3-butadiene,
25 isoprene, piperylene, phenylbutadiene, 3,4-dimethyl-1,3-hexadiene, 4,5-diethyl-1,3-octadiene, etc.), and preferably conjugated diolefins containing 4 to 9 carbon atoms.

The specific examples of the alkenyl aromatic hydrocarbon copolymerizable with the conjugated diene compound may include styrene, alkyl-substituted styrene, alkoxy-substituted styrene, or vinyl aryl compounds such as 2-vinyl pyridine, 4-vinyl pyridine,

vinyl naphthalene, or alkyl-substituted vinyl naphthalene.

Subsequently, a terminating agent of the same equivalent as the living polymer is added so as to deactivate the terminal of the living polymer. The terminating agent as used herein can be selected from amines, esters, ketones, or halogen compounds. The specific
5 examples of the terminating agent may include benzyl chloride, benzyl bromide, benzyl iodide, methyl chloride, methyl bromide, methyl iodide, ethyl chloride, ethyl bromide, ethyl iodide, butyl chloride, butyl bromide, butyl iodide, acetone, methylisobutylketone, diphenylketone, methanol, ethanol, isopropylalcohol, butanol, phenol, cresol, 2,6-di-t-butyl-4-methyl phenol, ethylacetate, butylacetate, trimethylsilylfluoride,
10 trimethylsilylchloride, trimethylsilylbromide, trimethylsilyliodide, triethylsilylfluoride, triethylsilylchloride, triethylsilylbromide, triethylsilyliodide, tributylsilylfluoride, tributylsilylchloride, tributylsilylbromide, tributylsilyliodide, triphenylsilylfluoride, triphenylsilylchloride, triphenylsilylbromide, or triphenylsilyliodide.

The hydrogenation reaction of the present invention is performed using a polymer
15 prepared by polymerizing a conjugated diene in an inert solvent.

The term "inert solvent" as used herein refers to a hydrocarbon solvent not reactive to any reactant in the hydrogenation reaction. The specific examples of the inert solvent may include aliphatic hydrocarbons (e.g., n-pentane, n-hexane, n-heptane, or n-octane); aliphatic cyclic hydrocarbons (e.g., cyclohexane, or cycloheptane); ethers (e.g.,
20 diethylether, or tetrahydrofuran); or mixtures of these compounds.

Alternatively, aromatic hydrocarbons such as benzene, toluene, xylene, or ethylbenzene can be used so long as their aromatic double bond is not hydrogenated in the selected hydrogenation condition.

After the addition of the terminating agent to deactivate the active terminal of the
25 living polymer, the conjugated diene polymer is selectively hydrogenated using an organotitanium compound represented by the formula 1 and a highly active lithium hydride having a precisely controlled particle diameter as prepared from a reactor equipped with a high-speed injection nozzle.

The process for preparing a highly active lithium hydride having a precisely
30 controlled particle diameter from a reactor equipped with a high-speed injection nozzle includes adding hydrogen to alkyl lithium.

The use of a general batch reactor, in which a hydrogen gas is added to an alkyl lithium mixing container through a sparger, requires a vigorous stirring, such as stirring at 1000 rpm or more, in order to reduce the reaction time and, for a larger-scaled reaction, delays the end point of the reaction, and increases the particle diameter with a rapid deterioration of the activity as a reducing agent. It is therefore actually impossible to prepare highly active lithium hydride having a precisely controlled particle diameter on a commercial business scale using the conventional batch reactor. Such a gas-liquid reaction process mainly depends on efficiency of the gas contact device, gas solubility, and temperature. Contrarily, the present invention uses a reactor equipped with a high-speed injection nozzle for adding hydrogen to alkyl lithium to control the particle diameter of lithium hydride within 2000 nanometers, preferably within 500 nanometers. Advantageously, the use of a reactor equipped with a high-speed injection nozzle as in the present invention hardly affects the particle diameter and activity of lithium hydride in the preparation process on a commercial business scale. With the reactor having a high-speed injection nozzle, the reaction is performed at a temperature of 0 to 30 °C with a hydrogen pressure of 0 to 50 kgf/cm², preferably 5 to 20 kgf/cm².

In the addition reaction of hydrogen to alkyllithium, a Lewis base is used to enhance the reactivity of the alkyl lithium. The Lewis base as used herein includes ethers such as diethylether or tetrahydrofuran. The added amount of the Lewis base is preferably in the range of 2- to 20-fold moles of the alkyl lithium. If the mole ratio of the Lewis base to alkyl lithium is less than 2, then the activity is deteriorated to require too much time to reach the end point of the reaction; otherwise, if the mole ratio of the Lewis base to alkyl lithium exceeds 20, then the overuse of the expensive ethers is much uneconomic and possibly causes side reactions.

The catalyst for the hydrogenation reaction of the present invention is an organotitanium compound represented by the formula 1, and prepared by dissolving or suspending a bis(cyclopentadienyl)titanium compound or a monocyclopentadienyl titanium compound in an appropriate solvent.

The specific examples of the organotitanium compound represented by the formula 1 may include a bis(cyclopentadienyl)titanium compound selected from the group consisting of bis(cyclopentadienyl)titanium difluoride, bis(cyclopentadienyl)titanium

dichloride, bis(cyclopentadienyl)titanium dibromide, bis(cyclopentadienyl)titanium diiodide, bis(cyclopentadienyl)titanium dicarbonyl, bis(cyclopentadienyl)titanium dimethyl, bis(cyclopentadienyl)titanium diethyl, bis(cyclopentadienyl)titanium dibutyl, bis(cyclopentadienyl)titanium dibenzyl, bis(cyclopentadienyl)titanium dihexyl, or
5 mixtures of these compounds; a monocyclopentadienyl titanium compound selected from the group consisting of monocyclopentadienyl(2,6-di-t-butyl-4-methylphenoxy)titanium difluoride, monocyclopentadienyl(2,6-di-t-butyl-4-methylphenoxy)titanium dichloride, monocyclopentadienyl(2,6-di-t-butyl-4-methylphenoxy)titanium dibromide, monocyclopentadienyl(2,6-di-t-butyl-4-methylphenoxy)titanium diiodide,
10 monocyclopentadienyl(2,6-di-t-butylphenoxy)titanium dichloride, or monocyclopentadienyl(2,6-di-t-butyl-4-methylphenoxy)titanium dichloride; or mixtures of the bis(cyclopentadienyl) titanium compound and the monocyclopentadienyl titanium compound.

The added amount of the hydrogenation catalyst is preferably, based on 100 g of
15 the polymer, 0.01 to 20 mmol, more preferably 0.05 to 2 mmol.

The mole ratio of the lithium hydride to the titanium in the hydrogenation catalyst is preferably 2:1 to 30:1.

If the mole ratio of the lithium hydride to titanium in the hydrogenation catalyst is less than 2:1, then the activity of the hydrogenation catalyst is deteriorated to require too
20 much time to reach the end point of the reaction and poor hydrogenation yield; otherwise, if the mole ratio of the lithium hydride to titanium in the hydrogenation catalyst exceeds 30:1, then the overuse of the expensive lithium hydride is much uneconomic and would cause the requirement of the unnecessary neutralization process during the finishing process.

25 Using the hydrogenation catalyst, hydrogen can be selectively added to the unsaturated double bonds of the conjugated diene part in the homopolymer of the conjugated diene monomers or in the copolymer with a copolymerizable vinyl-substituted aromatic monomers. Such polymers would be a random or block copolymer and have a molecular weight of 500 to 1,000,000.

30 In the hydrogenation reaction of the present invention, the concentration of the polymer is, based on the solvent, 1 to 50 wt.%, preferably 5 to 25 wt.%.

The hydrogenation reaction of the present invention is performed in the procedures of maintaining a polymer solution at a predetermined temperature in the hydrogen or inert gas atmosphere, adding a hydrogenation catalyst with/without stirring, and introducing hydrogen gas with a predetermined pressure.

5 The term “inert gas” as used herein refers to a gas not reactive to any reactant of the hydrogenation reaction. Air or oxygen, which oxidizes or decomposes the hydrogenation catalyst to deteriorate the activity of the catalyst, is not preferred.

For the hydrogenation reaction, the reaction temperature is in the range of 0 to 150 °C. The reaction temperature of below 0 °C deteriorates the hydrogenation reaction
10 rate as well as the activity of the catalyst, thus uneconomically requiring an excessive amount of the catalyst, and possibly causes precipitation of the polymer due to the insolubility of the hydrogenated polymer. Contrarily, the reaction temperature of above 150 °C produces many different catalytic species or decomposes the catalyst to cause gelation or decomposition of the polymer, and readily leads to a hydrogenation of the
15 aromatic double bonds to deteriorate the selectivity of the hydrogenation. More preferably, the reaction temperature is in the range of 50 to 140 °C.

The pressure of the hydrogen used for the hydrogenation reaction is not specifically limited and preferably in the range of 1 to 100 kgf/cm². With the hydrogen pressure of less than 1 kgf/cm², the hydrogenation reaction rate decreases, requiring an
20 excessive amount of the catalyst. With the hydrogen pressure of more than 100 kgf/cm², gelation of the polymer occurs actually as an unnecessary side reaction. More preferably, the hydrogen pressure is in the range of 2 to 30 kgf/cm². The optimal hydrogen pressure is selected in relation to the other hydrogenation conditions such as the added amount of the catalyst. Substantially, a high hydrogen pressure is preferred with a small amount of the
25 hydrogenation catalyst.

The hydrogenation reaction time of the present invention is typically several to 1,440 minutes, preferably 30 to 360 minutes. The hydrogenation reaction of the present invention can be performed in the batch, continuous or other reaction type.

The progress of the hydrogenation reaction can be monitored by measuring the
30 consumed amount of hydrogen.

In the present invention, a hydrogenated polymer can be produced so that more

than 50 %, preferably more than 90 % of the unsaturated double bonds of the conjugated diene unit are hydrogenated. More preferably, in the case of hydrogenating a copolymer of conjugated diene and vinyl-substituted aromatic hydrocarbon, a copolymer of which the unsaturated double bonds of the conjugated diene unit is selectively hydrogenated can be
5 obtained to provide more than 90 % of the hydrogenation yield in the unsaturated double bond of the conjugated diene unit, and less than 5 % of the hydrogenation yield in the aromatic double bond.

By using a highly active lithium hydride having a precisely controlled particle diameter as prepared from a reactor equipped with a high-speed injection nozzle, the
10 present invention acquires a relatively high hydrogenation reaction rate and excellent reaction reproducibility, and improves the inefficiency such as long reaction time and uneconomic aspect of requiring high pressure and high-speed stirring in the conventional method of treating the active terminal of the living polymer or the alkyl lithium with hydrogen gas.

15

DETAILED DESCRIPTION OF THE INVENTION

Now, the present invention will be described in further detail by way of the following examples, which are not intended to limit the scope of the present invention.

Synthesis Example 1: Synthesis of highly active lithium hydride (LiH) from reactor equipped with high-speed injection nozzle.

980g of an n-butyl lithium solution (in 2M cyclohexane) and 2,160g of tetrahydrofuran were added to 8,900g of cyclohexane in a loop-type 15l-reactor equipped with a high-speed injection nozzle, a circulating pump and a heat exchanger in the inert
25 gas atmosphere. The reaction was performed for one hour while the temperature of the reactor was kept at the room temperature (within 30 °C) and the gaseous hydrogen was injected into the reactor through the high-speed injection nozzle to maintain the hydrogen pressure of 10 kgf/cm². The mixed solution was turned to a white suspension. The end
point of the reaction was checked by visual inspection when there was no change in color
30 of the partly collected solution with a styrene monomer added. If there were non-reacted alkyl lithium in the solution, then it would instantly appear yellowish due to the

polymerization reaction with the styrene monomer. After one hour of the reaction, the end point was determined through a styrene test. The mixed solution was then analyzed in regard to the particle diameter with a particle size analyzer.

5 The particle diameter of the lithium hydride measured with the particle size analyzer was 280 nm in z-average value.

Synthesis Example 2: Synthesis of lithium hydride (LiH) from batch reactor.

980g of an n-butyl lithium solution (in 2M cyclohexane) and 2,160g of tetrahydrofuran were added to 8,900g of cyclohexane in a 15l-autoclave reactor in the
10 inert gas atmosphere. The reaction was performed for one hour in the reactor kept at the room temperature with stirring at 1,000 rpm, and the gaseous hydrogen was injected into the reactor to maintain the hydrogen pressure of 10 kgf/cm². To determine the end point of the reaction, part of the solution collected was reacted with a styrene monomer and instantly turned yellow as checked by visual inspection. The reason of this change of color
15 was because the non-reacted alkyl lithium remaining in the solution participated in the polymerization reaction with the styrene monomer and turned yellow. After one more hour of the reaction, the solution still appeared yellowish through the reaction with the styrene monomer and, after two more hours of the reaction, the reaction approached the end point. Subsequently, the mixed solution was analyzed in regard to the particle diameter with a
20 particle size analyzer.

 The particle diameter of the lithium hydride measured with the particle size analyzer was 3,987 nm in z-average value.

Synthesis Example 3: Solid lithium hydride for commercial purpose.

25 A lithium hydride powder commercially available with 30 mesh was suspended in cyclohexane to prepare a suspension.

Synthesis Example 4: Synthesis of low-viscosity styrene-butadiene-styrene block copolymer.

30 11g of tetrahydrofuran, 124g of a styrene monomer, and 16mmol of n-butyl lithium were added to 4,800g of cyclohexane in a 10l-autoclave reactor. After 30 minutes

of polymerization, 552g of a 1,3-butadiene monomer was added to the reactor and kept for one hour of polymerization. Finally, 124g of a styrene monomer was added and kept for 30 minutes of polymerization. The active terminal of the living polymer thus obtained was deactivated with trimethylsilyl chloride added in the same mole as the polymerization
5 initiator, n-butyl lithium. The polymer thus obtained was a styrene-butadiene-styrene block copolymer of which the bound styrene content was 31.0%, the 1,2-vinyl bond content of the 1,3-butadiene unit was 38.5%, and the number average molecular weight was about 50,000.

10 **Synthesis Example 5: Synthesis of medium-viscosity styrene-butadiene-styrene block copolymer.**

11g of tetrahydrofuran, 120g of a styrene monomer, and 13mmol of n-butyl lithium were added to 4,800g of cyclohexane in a 10l-autoclave reactor. After 30 minutes of polymerization, 560g of a 1,3-butadiene monomer was added to the reactor and kept for
15 one hour of polymerization. Finally, 120g of a styrene monomer was added and kept for 30 minutes of polymerization. The active terminal of the living polymer thus obtained was deactivated with trimethylsilyl chloride added in the same mole as the polymerization initiator, n-butyl lithium. The polymer thus obtained was a styrene-butadiene-styrene block copolymer of which the bound styrene content was 29.6%, the 1,2-vinyl bond
20 content of the 1,3-butadiene unit was 40.5%, and the number average molecular weight was about 65,000.

Synthesis Example 6: Synthesis of high-viscosity styrene-butadiene-styrene block copolymer.

25 11g of tetrahydrofuran, 116g of a styrene monomer, and 4.5mmol of n-butyl lithium were added to 5,600g of cyclohexane in a 10l-autoclave reactor. After 30 minutes of polymerization, 469g of a 1,3-butadiene monomer was added to the reactor and kept for one hour of polymerization. Finally, 115g of a styrene monomer was added and kept for 30 minutes of polymerization. The active terminal of the living polymer thus obtained was
30 deactivated with trimethylsilyl chloride added in the same mole as the polymerization initiator, n-butyl lithium. The polymer thus obtained was a styrene-butadiene-styrene

block copolymer of which the bound styrene content was 33.0%, the 1,2-vinyl bond content of the 1,3-butadiene unit was 39.5%, and the number average molecular weight was about 160,000.

5 **Synthesis Example 7: Synthesis of styrene-butadiene random copolymer.**

100g of tetrahydrofuran, 105g of a styrene monomer, 696g of a butadiene monomer, and then 8.0mmol of n-butyl lithium were added to 4,800g of cyclohexane in a 10l-autoclave reactor. The reactant mixture was subjected to polymerization for one hour. The active terminal of the living polymer thus obtained was deactivated with
10 trimethylsilyl chloride added in the same mole as the polymerization initiator, n-butyl lithium. The polymer thus obtained was a styrene-butadiene random copolymer of which the bound styrene content was 13.3%, the 1,2-vinyl bond content of the 1,3-butadiene unit was 57%, and the number average molecular weight was about 100,000.

15 **Synthesis Example 8: Synthesis of butadiene homopolymer.**

800g of a butadiene monomer and then 8.2mmol of n-butyl lithium were added to 4,800g of cyclohexane in a 10l-autoclave reactor. The reactant mixture was subjected to polymerization for 2 hours. The active terminal of the living polymer thus obtained was deactivated with trimethylsilyl chloride added in the same mole as the polymerization
20 initiator, n-butyl lithium. The polymer thus obtained was a butadiene homopolymer of which the 1,2-vinyl bond content of the butadiene unit was 10%, the cis content was 35% and the number average molecular weight was about 98,000.

Examples 1 to 5

25 2,800g of a polymer solution containing 400g (310g in the case of synthesis example 6) of each polymer prepared in the respective Examples 4 to 8 was added to a 5l-autoclave reactor, and the hydrogen gas was blown into the reactor. The highly active lithium hydride solution prepared in the Synthesis Example 1 was injected into the reactor so that the LiH/Ti mole ratio was 15/1. The mixture was then heated to 80°C.
30 Subsequently, as a main catalyst, 0.2 mmol of monocyclopentadienyl(2,6-di-t-butyl-4-methylphenoxy)titanium dichloride per 100g of the polymer was added to the polymer

solution. The hydrogenation reaction was performed in the reactor with the hydrogen pressure of 10 kgf/cm² with stirring at 400 rpm (rotations per minute) for 180 minutes. After the completion of the reaction, the reactor was cooled down with the pressure lowered to the ambient pressure, and the reaction solution was added in methanol to precipitate the polymer.

The hydrogenated polymer thus obtained was then subjected to ¹H-NMR analysis. As a final result, the hydrogenation yields of the butadiene unit and the styrene unit are presented in Table 1.

Table 1

Example	1	2	3	4	5
Polymer	S4	S5	S6	S7	S8
LiH	S1				
Main catalyst	Monocyclopentadienyl (2,6-di-t-butyl-4-methylphenoxy) titanium dichloride				
Hydrogenation yield of Butadiene Unit (%) after 60 min	99	99	98	98	98
Hydrogenation yield of Butadiene Unit (%) after 120 min	99	99	98	98	99
Hydrogenation yield of Butadiene Unit (%) after 180 min	99	99	99	98	99
Hydrogenation yield of Styrene Unit (%)	<1	<1	<1	<1	<1

Note) S1: Synthesis Example 1
 S4: Synthesis Example 4
 S5: Synthesis Example 5
 S6: Synthesis Example 6
 S7: Synthesis Example 7
 S8: Synthesis Example 8

Comparative Examples 1 to 5

The hydrogenation procedures were performed in the same manner as described in the above Examples, excepting that the polymers prepared in the Synthesis Examples 4, 5 and 6 were used with lithium hydride prepared in the Synthesis Examples 2 and 3 as a cocatalyst. The results are presented in Table 2.

Table 2

Example	1	2	3	4	5
Polymer	S4	S5	S6	S4	S5
LiH	S2			S3	
Main catalyst	Monocyclopentadienyl (2,6-di-t-butyl-4-methylphenoxy) titanium dichloride				
Hydrogenation yield of Butadiene Unit (%) after 60 min	43	25	10	N/R	N/R
Hydrogenation yield of Butadiene Unit (%) after 120 min	45	26	11	N/R	N/R
Hydrogenation yield of Butadiene Unit (%) after 180 min	45	26	11	N/R	N/R
Hydrogenation yield of Styrene Unit (%)	<1	<1	<1	N/R	N/R

Note) S2: Synthesis Example 2
S3: Synthesis Example 3
S4: Synthesis Example 4
S5: Synthesis Example 5
S6: Synthesis Example 6
N/R : No reaction

Examples 6 to 9

The hydrogenation procedures were performed in the same manner as described in the above Examples, excepting that Bis(cyclopentadienyl)titanium dichloride was used as a main catalyst. The results are presented in Table 3.

Table 3

Example	6	7	8	9
Polymer	S4	S5	S6	S7
LiH	S1			
Main catalyst	Bis(cyclopentadienyl)titanium dichloride			
Hydrogenation yield of Butadiene Unit (%) after 60 min	99	98	98	98
Hydrogenation yield of Styrene Unit (%)	<1	<1	<1	<1

Note) S1: Synthesis Example 1

Examples 10 to 13

The hydrogenation procedures were performed in the same manner as described

in the above Examples, excepting that the lithium hydride prepared in the Synthesis Example 1 had a LiH/Ti mole ratio of 4/1, 10/1, 15/1 or 30/1. The results are presented in Table 4.

5

Table 4

Example	10	11	12	13
Polymer	S4			
LiH/Ti (mole ratio)	4/1	10/1	15/1	30/1
LiH	S1			
Main catalyst	Bis(cyclopentadienyl)titanium dichloride			
Hydrogenation yield of Butadiene Unit (%) after 60 min	93	98	99	99
Hydrogenation yield of Styrene Unit (%)	<1	<1	<1	<1

Note) S1: Synthesis Example 1
S4: Synthesis Example 4

Examples 14, 15 and 16: Reproducibility Test

10

The hydrogenation procedures were performed for the polymer prepared in the Synthesis Example 4 with the reaction of the Example 6, i.e., while the lithium hydride of the Synthesis Example 1 had a fixed LiH/Ti mole ratio of 15/1. And, these procedures were repeated three times. The results are presented in Table 5.

15

Table 5

Example	6	14	15	16
Polymer	S4			
LiH/Ti (mole ratio)	15/1			
Lithium Hydride	S1			
Main catalyst	Bis(cyclopentadienyl)titanium dichloride			
Hydrogenation yield of Butadiene Unit (%) after 60 min	99	99	99	99
Hydrogenation yield of Styrene Unit (%)	<1	<1	<1	<1

Note) S1: Synthesis Example 1
S4: Synthesis Example 4

As described above, the polymer hydrogenation process using a highly active lithium hydride of a precisely controlled particle diameter as prepared from a reaction equipped with a high-speed injection nozzle guarantees stable hydrogenation reaction rate and high reproducibility, solves the uneconomic problem of requiring high pressure and

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high-speed stirring in the conventional methods of terminating the active terminal of a living polymer by hydrogen gas, reduces the reaction time through an enhanced reactivity, and provides a high hydrogenation activity by quantitatively controlling the LiH/Ti mole ratio in the hydrogenation of conjugated diene polymers having different molecular

5 weights.